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PRODUCTIVITY MEASUREMENT:
APPLICATIONS TO THE AUTOMOBILE INDUSTRY

by

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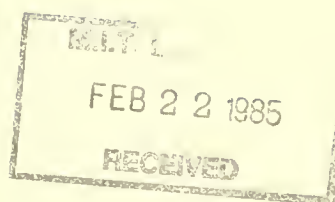
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I. INTRODUCTION

Given our general task of analyzing industry health, its components and possible solutions, we begin by examining what is considered to be a major component--productivity. Of course, a prodigious amount of research effort has been focused on this issue and it is not our purpose here to reproduce or reiterate what others have done. What we will do, however, is to examine existing research and make our own recommendation in terms of our purposes in this project. We are interested in understanding productivity at the industry and firm level (as opposed to economic sector or individual level) and based on this understanding develop a model that will provide meaningful strategic signals to participants.

What is critical then, as we proceed in our analysis, is the development of criteria relevant to our inquiries to be utilized in evaluating both existing measures of productivity and ones that might be developed. We identify three main areas of concern: 1) the theoretical and statistical soundness of a measure; 2) the feasibility of the measure; and 3) the usefulness of a measure. We will now need to elaborate on these criteria in order to make them more operational, but before we do so we will make two comments.

First, much of the research and the ensuing discussion has focused on the first two elements, especially the first. Little effort, however, has been directed at addressing the third item. Thus, we find ourselves in a situation where a measure may indicate a change in productivity has occurred but we are unable to understand the implications of such a change or determine what actions might be taken to deal with it.

Second, one should recognize that these three criteria are not independent of one another but rather there are certain trade-offs among them e.g., what is theoretically attractive may not be practically attainable. Therefore, as we elaborate on these categories we should keep in mind that such trade-offs are implicit in our discussion.

II. CRITERIA

A. Soundness

The first area of concern is the theoretical and statistical soundness of a measure. The measure chosen should be theoretically based on solid economic principles and statistically sound. The definition of productivity and its growth rate is rather arbitrary, because the concept itself is not a derivative of first principles but rather a quantification of efficiency. As such, it is usually considered as being the output per given level of input, where outputs and inputs can be measured in terms of physical units, value, or value-added. However, the choice of which measure to use is not a trivial question--indeed this issue has generated hundreds of pages of discussion. We see basically four areas of concern that need some resolution--consistency, homogeneity, robustness and validity. Let us now examine each of these items.

1. Consistency

The measure should be as free of interdependencies as possible. Where these exist, they should be explicitly recognized and taken into account. If not there may be double-counting depending on the consonance of factors.

The measure should have clearly stated assumptions. If the measure is i) to have validity and ii) to be useful for decision-making, it is essential that the underlying assumptions be understood so that a comparison between the current results and these assumptions can be made in order to determine significant differences which may either dampen or heighten results.

Causal relationships implied in the measure should be explicitly stated. A particular measure only has meaning in that it reflects not only certain assumptions but also cause-effect relationships. The context in which it is used generates meaning. What is critical is that these relationships be clearly delineated for decision-making purposes, i.e. what are the hypotheses that are implicitly being proposed in the usage of a particular measure.

2. Homogeneity

Generally speaking, homogeneity can be defined as the quality of being uniform or having common properties--thus also implying consistency in measurements at any moment in time and over time. Thus, if we want to quantify output and inputs we must have some way of aggregating different quantities into meaningful data. If we were to use physical units, we would encounter the problem of how to count many different types of products. For example, with outputs do we count a large, luxury automobile the same as a small, fuel-efficient, standardized one? With inputs we are faced with labor of varying ages and skills, with capital of various ages and technological capabilities, and with intermediate inputs of differing qualities (e.g. grades of oil). We need some integrating mechanism that allows us to aggregate these so their new values are meaningful.

Also, aggregation may hide certain critical data. For example, if one looks at total productivity (i.e. using all inputs in the denominator) a shift in the capital-labor ratio

would be hidden. Similarly, there may be no indication whether the technology has changed, causing a change in productivity.

If one looks at value of the outputs over inputs (Price times Quantity), this solves some of the homogeneity problems by reducing everything to a common measure, dollars. However, there are problems with using this in that the actual efficiency of operation may not be accurately portrayed because the amount that is contributed by the firm is hidden. For example, the price of a good sold by the firm may be quite high (and thus showing a high value), but it may reflect a high cost of intermediate inputs.

In a pure economic model of the free market, the price mechanism is considered to be the integrating mechanism for homogenization. In this model many buyers and sellers convene in a common place, the market, where information is freely exchanged and the price of goods is determined through an impersonal mechanism, the market's collective free will. This is a transformation mechanism, a kind of a "black box" into which sellers and buyers enter in order to maximize their profits/utilities. The output of this "black box" is a general equilibrium between fully regimented buyers and sellers where price (\$/physical unit) plays the role of the interface element. It can be proven that when these ideal conditions prevail, the price of an input or output good reflects the marginal cost of a physical unit of the input or output.

This abstraction of market processes is very attractive due to its simplicity and strong explanatory power, but it has

certain limitations. In real life, both utility assessments and production processes involve elements such as information impactedness, time, and uncertainty which confound the model.

Information impactedness is created because human and technological limits constrain the number of information channels or the flow rate of information, or both. For example, technological innovation may be more frequent in firm A than firm B, because firm A employs more and better trained engineers than firm B or because firm A monitors its environment more carefully than firm B. The inequalities of information impart special advantages to firms, which may allow them to set prices, especially in the short run.

Time creates problems because of the "roundaboutness" of most production processes. For example, firm A may decide to retool, but it may take years before retooling is accomplished. Thus, a long-run equilibrium may not be a practically viable concept in explaining real-life situations.

Finally, the existence of uncertainty and its quantitative measure, risk, further confound the model. In most buy/sell decisions market process outcomes are generally not deterministic, but cover an entire probabilistic spectrum. These confounding elements create market power which allows firms to differentially take advantage of such situations, depending on their strategic profile. Strategies taken by firms may either exacerbate or diminish the degree to which price exceeds marginal cost within an industry, i.e. strategies in turn affect these three elements. To the extent this is true, then

price will reflect not only the marginal cost to produce an additional physical unit, but will also reflect market or strategic power.

All this discussion is important to productivity measures and measurement because the price of output goods is reflected in wages, material costs, and the value-added of inputs. Hence productivity measures which use numerators and denominators expressed in dollar terms are directly affected by price aberrations. If price does not exclusively reflect marginal cost, the productivity measurements will reflect not only technico-economic value and the efficiency of production processes but also competitive advantage and the effectiveness of the strategic positioning (e.g. vertical integration).

We can observe some of these disturbing factors in the U.S. automobile industry. Over the past twenty-five years, we have seen a) an increasingly strong labor union with all its related side effects; b) a relatively competitive set of suppliers for direct materials and parts; and c) an oligopolistic industry structure prior to around 1965 and a rather competitive industry structure after that date, when the surge of European and Japanese manufacturers transformed the American automobile market into a world automobile market.

All these matters, then mitigate the effectiveness of price as a homogenizing mechanism. The problem, however, in terms of measurement is how to quantify the various elements in order to arrive at a "pure" price value.

Furthermore, there is an additional problem with using price in a time-series model--the effects of inflation. We must be sure we are comparing dollar values over time that reflect the same relative value. Of course, this can be rectified somewhat by deflating monetary values according to some index such as the Consumer Price Index.

However, while this may attenuate effects in the aggregate, it may also hide or disguise critical data. In fact, the rate of inflation may vary from industry to industry, depending again on the structure of the industry, demand and supply conditions, etc. In like manner, the degree of interrelatedness of an industry to others (with their respective rates) may differentially impact an industry. Therefore, while these effects may be difficult to separate and account for, the limitations of the measure should be recognized. And hopefully, future research will uncover methods for dealing with these phenomena.

3. Robustness

Another statistical concern is whether or not a measure is robust or efficient in terms of its ability to represent the distribution of variance in a given population of data.

Statistically speaking, a strong argument can be made for using an estimator that is reasonably efficient for any kind of population shape. Efficiency is defined in the general case as the ratio of the Mean Square Errors (MSE) of two estimators; we say that the relative efficiency of estimator X_1 compared to X_2 is:

$$\text{efficiency} = \frac{\text{MSE}(X_2)}{\text{MSE}(X_1)} = \frac{E(X_2 - X)^2}{E(X_1 - X)^2}$$

where

E = expected value operator

X = target value

$X_{1,2}$ = distribution of estimators X_1, X_2 biased or unbiased.

In the case of unbiased estimators, the criterion of efficiency boils down to the ratio of the variances of two estimators. Hence we say that the relative efficiency of an unbiased estimator X_1 compared to X_2 is

$$\text{efficiency} = \frac{\text{Var}(X_2)}{\text{Var}(X_1)} = \frac{E(\bar{X}_2 - X)^2}{E_1(X - \bar{X}_1)^2}$$

where

E = expected value operator

$\bar{X}_{1,2}$ = means of unbiased distributions X_1 and X_2 ($\bar{X}_1 = \bar{X}_2 = \bar{X}$)

$X_{1,2}$ = distribution of unbiased estimators X_1, X_2

An estimator which is free of the assumption that the population distribution is normal, and is therefore reasonably efficient compared to a normally distributed estimator is called robust, distribution-free, or nonparametric.¹

¹T. Wonnacott, R. Wonnacott, (1977), p. 193.

For our purposes we are going to examine the robustness of various productivity measures by adapting the above methodology, as we shall soon detail in Section V.

4. Validity

A test is said to be statistically valid if its probability values and confidence intervals are correct as specified. In our test we employed mean and variance out of the population of residuals. Since the total number of residuals will be small (probably twenty-five years), the student-t distribution may be more appropriate than the normal distribution for the determination of probabilities p_i , for $i = 1, 2..k$.

Henceforth we decided to use the Student distribution for the calculation of P_i 's

$$\text{of } P_i = \Pr\left(\frac{X_{i-1} - M}{S} < X < \frac{X_i - M}{S}\right) \quad \begin{array}{l} \text{From distribution of Student-t} \\ \text{for } n-1 \text{ (generally 24) degrees} \\ \text{freedom} \end{array}$$

M = Mean

S = Standard deviation

v B. Practicality

The second area of concern is the practicality of the measure, for what may be theoretically attractive may be unrealistic in terms of practically calculating the measure. Thus, the following criteria should be utilized:

- a) The elements utilized in the measure of productivity must be amenable to measurement. They must be reasonably quantifiable.
- b) The measure should utilize data that is feasible to collect. Of course, the best situation is one where data are already

available. The measure should not call for data which are by nature unavailable or is prohibitively expensive to gather.

✓ C. Utilization

The final area involves the utilization of the measure. The measure chosen may be theoretically attractive, as well as feasible, yet it may convey no useful information to interested parties.

- a) The measure should be useful for inter-firm, intertemporal, and inter-industry analysis. This implies that national aggregates will not be useful for our purposes. The measure must be disaggregated sufficiently so that the resultant indicators will provide information that will be useful to the industry as well as to firms within that industry. The issues of averaging and standardization should also be considered here. If there is an excessive amount of these, figures may hide critical information rather than provide it.
- b) The measure should provide strategic signals to decision-makers. Too often measures indicate a change taking place but provide no meaningful information as to exactly what has occurred and what actions might be appropriate. According to the causal relationships hypothesized in the measure (mentioned above), interested parties should be able to monitor certain indices to alert parties to changes and possible causes. These signals then provide a feedback mechanism, and as such can be considered as part of a firm's (or industry's) control system.
- c) Related to the point above, the measure must be in a form that not only can be utilized by decision-makers, but also will be. If it bears little resemblance to the decision-makers' frame of reference, they may not utilize it.

D. Choice of the Appropriate Measure

From the previous discussion we can see that it will be difficult to find a single measure which will meet all of the criteria, especially since some are at cross-purposes with one another. In this case priorities must be set among the criteria. It is our opinion that while the first two areas of concern mentioned above are certainly quite important, it is the third area that should receive more emphasis than it has before. Otherwise any measure that is calculated is merely data and not information.

If we stress the utilization of the measure, then we may find that a single measure is not the best approach, but rather we may find that we may need a number of measures utilized simultaneously that monitor different elements and provide different signals to decision-makers. It also may be the case that different measures are appropriate at different times and in different situations. We also stress that if the measure(s) is to be utilizable, the underlying assumptions and causal relations must be understood. If this is the case, it may be that what needs to be monitored is not necessarily the one productivity measure but rather sub-elements of which it is composed or sub-sub-elements. If we are not able to do this, not only may we not have indications of what remedies might be desirable but also we may not receive the information in a sufficient span of time in which remedial action will be effective.

III. SOME CURRENT MEASURES

Theory and empirical research have established a number of productivity and productivity growth rate measures that are currently being used. Here we will attempt to briefly examine some of the most commonly used measures in light of our criteria developed in Part II.

A. Bureau of Labor Statistics (BLS) Measure

BLS has traditionally defined productivity as output per man-hour. They use Gross National Product as the output measure and average worker hours paid as the measure of man-hours for input. Hence:

$$\text{BLS productivity measure} = \frac{\text{GNP}}{\text{average worker-hours paid}}$$

The BLS method is typical of the Growth Accounting "school" of productivity measures in that averaged accounting data is utilized in calculating the measure. It is also a partial factor productivity measure i.e. it looks at only one factor input--in this case, labor. Although there is nothing conceptually wrong with partial productivity measures, the BLS measure, at least in terms of our criteria, is deficient in the following respects:

1. Labor input in the denominator is not homogeneous because hours worked by skilled and unskilled workers are averaged without using any weights.
2. It is short in its inclusiveness. Data on hours worked cover only production workers; however, from a managerial point of view, all workers--support as well as production--are part of the cost function of the firm and the industry.

B. Gollop and Jorgenson's (G-J) Measure

G-J define productivity as value-added of output over value-added of input, both measured in constant dollars. Hence

$$\text{G-J measure} = \frac{\text{Value-added of Output}}{\text{Value-added of Input}}$$

The value of output is net of indirect business taxes, sales and excise taxes as well as trade and transportation margins associated with delivery of the output. The value-added of input includes transportation costs and all taxes on primary and intermediate inputs. Furthermore, labor input is adjusted for sex, age, employment class, hours paid vs. hours worked, and employees' total earnings vs. earnings from a specific job. The value of capital is adjusted for replacement rate, technological change, and land appreciation.

The G-J method is typical of the Production function "school" of productivity measures as regression analysis is used in order to determine the coefficients of a production function using input-output data collected and adjusted as just described. In contrast with the BLS measure, the G-J measure is a total factor productivity measure.

There are some weak points in their approach:

- 1) They assume constant returns to scale in their production function, which is often unrealistic.
- 2) The G-J measure of productivity growth rate is defined as

$$\left(\frac{dY/dt}{dX/dt}\right)\left(\frac{Y}{X}\right) \text{ whereas a better specification might be}$$

$$\frac{dY/dt}{Y} - \frac{dX/dt}{X} \quad (\text{see Berndt, 1980}).$$

- 3) The elaborate adjustments of labor input may be of great value for economic analysis aimed to facilitate public policy decisions, but from a managerial point of view, all of the adjustments would be reflected in the market price for labor.

C. Denison's (D) measure (1974)

D defines productivity as value added of output over value added of input, both in constant dollars. The value of output and input are adjusted as elaborately as by the G-J method described above.

The D method is similar to BLS in that it falls in the growth accounting "school" but it differs in that D's measure considers total productivity. One of its weaknesses is the same as (3) for G-J, i.e. that the elaborate labor adjustments could be corrected by using the market price of labor.

D. Perry's (P) measure (1977)

P defines productivity as Gross National Product over employed workers, where the labor force is adjusted for age, sex, potential labor force, and cyclical fluctuations in participation. Hence,

$$P \text{ measure} = \frac{GNP}{(1-\text{unemployment}) \times \text{Population}}$$

The P method is typical of the econometrics "school" of productivity measures because it uses a number of functional forms in order to achieve a good fit on the basis of input-output data collected and adjusted as described above. Also, this measure looks at partial factor productivity rather than total factors. Since GNP is used in the denominator, this measure suffers from the same deficiency as (1) under BLS. In addition, Okun's Law is blindly invoked and used.

E. Norsworthy's (N) measure (1979)

N defined productivity as value added of output over value added of input, expressed in constant dollars. The value of output and input are adjusted as elaborately as the G-J and D methods described above. In addition, capital is adjusted for intersectoral shifts, composition, and nonproductive investments, such as pollution abatement equipment.

The N method is similar to G-J in that it is of the Production function "school", and looks at total factor productivity. As such it is weak in points (1) and (3) under G-J. However, N does not account for technological improvement, as do both G-J and D, which we feel is a shortcoming of the work.

F. Scheppach and Woehlcke's (S-W) measure (1975)

S-W defined productivity as value added of output over value added of input, both in constant dollars. The value of output is revenue net of the value of intermediate inputs adjusted for quality changes; the value of input is physical units multiplied by appropriate base prices (deflated indices) for aggregate labor, capital, and intermediate inputs. Hence

$$\text{S-W measure} = \frac{\text{Value added of output}}{P_L \cdot L + P_K \cdot K + P_{\text{int}} \cdot \text{Intermed. Inputs}}$$

The S-W method is also typical of the growth accounting "school" and uses total factor productivity.

However, the S-W approach is deficient in that the value of input in the denominator is quasi-homogeneous, because base prices (deflators) do not reflect substitution possibilities over the years.

IV. DATA

In order to test the properties of various measures, a data base is needed containing relevant data. We have examined many potential sources but our data have come primarily from two sources: annual reports and The Census of Manufactures. The former is a rich source of information on individual firms, and the latter is particularly useful in securing industry level data. We have also utilized Ward's Automotive Yearbook, the Bureau of Labor Statistics, and other sources for additional data.

For purposes of clarity, we provide a description of certain items which required some calculation on our part or which would be clarified by an explanation.

A. Industry Level Data

1. Industry Value Added:

Value added for an industry is calculated by The Census of Manufactures by taking the value of industry shipments (products manufactured plus receipts for services rendered) and subtracting from it the cost of inputs and adding to it the cost of changes in inventories.

2. Industry Total Payroll:

This includes the gross annual earnings paid to all employees in the industry who are on firms' payrolls. It includes all forms of compensation such as salaries, wages, bonuses, and benefits.

3. Industry Payroll of Production Workers:

This consist of gross annual earnings paid to the industry's production workers which are defined to be workers engaged in production operations, up through the working foreman level.

4. Industry Production Workers Hours:

This is hours paid at the plant level for the entire industry. It excludes hours paid for vacation, holidays, or sick leave.

5. Industry Capital Expenditures:

This refers to all costs which are chargeable to the fixed assets account and for which depreciation or amortization accounts are ordinarily maintained.

6. Industry Payroll:

The industry payroll indicates annual earnings paid to all hourly and salaried employees. Employee benefits are included in earnings, but stock options are not (stock options are not considered out-of-pocket costs and thus should not be included in earnings).

B. Firm Level Data

1. Value added:

As with value added on the industry level, this is calculated by subtracting inventory changes and material costs from sales, i.e.

$$VA = NS + (I_{t+1} - I_t) - M \quad (1)$$

where VA = Value Added; NS = Net Sales; $(I_{t+1} - I_t)$ = cost of the difference in inventory from one period to another; and M = material costs (all figures expressed in dollars). However, while net sales can be found in annual reports, the other items are not as readily secured. Nevertheless, we can use our knowledge of accounting to deduce the necessary information. We do know that the cost

of goods sold including administrative expenses (ACGS) consists of payroll (P) and material costs (M) less the costs associated with a change in inventory (I). That is,

$$ACGS = P + M - (I_{t+1} - I_t) \quad (2)$$

Thus,

$$M = ACGS - P + (I_{t+1} - I_t) \quad (3)$$

Substituting for M in equation (1) we get

$$VA = NS + (I_{t+1} - I_t) - [ACGS - P + (I_{t+1} - I_t)] \quad (4)$$

$$= NS + (I_{t+1} - I_t) - (I_{t+1} - I_t) - ACGS + P \quad (5)$$

$$= NS - ACGS + P \quad (6)$$

$$VA = \text{Operating Income} + \text{Payroll} \quad (7)$$

Fortunately, operating income and payroll can be gleaned from annual reports.

We have done so and this is what we call the unadjusted value added for a firm.

The reason it is unadjusted is that the cost of the difference in inventory is evaluated on a cost basis as opposed to a market-value basis. Therefore, when there is an addition to inventory in a particular period, value added will be underestimated, and similarly, when inventory is depleted, (i.e. Net Sales exceed goods produced), value added is overestimated. To correct or adjust for this, it is necessary that the difference between the market value of inventory and its cost, which is the profit margin, be added to the numerator of the productivity measure.

Thus, if all the goods produced in a period were sold, adjusted and unadjusted value added would be the same. If, however, either more (or less) goods are sold than produced, value added would change by the following amount:

$$\begin{aligned}\Delta(\text{VA}) &= \Delta(\text{inventory}) * \text{margin (difference between cost} \\ &\quad \text{and market value of inventory)} \\ &= (\text{current year inventory} - \text{previous year inventory}) \\ &\quad \times \frac{\text{Net Sales} - \text{Cost of Goods Sold} - \text{Depreciation}}{\text{Net Sales}}\end{aligned}$$

Therefore, our adjusted VA is the sum of operating income plus payroll plus the dollar value of the difference in inventory from one period to the next, i.e.

$$\text{Adj. VA} = \text{Operating Income} + \text{payroll} + \Delta \text{ value added due to inventory adjustment.}$$

2. Sales Value of Output

This is derived from Net Sales figures taken from annual reports that we have adjusted for inventory changes. It represents the market value of goods produced in a given period. If inventories decreased in a given period, this means more goods were sold than produced, and we thus subtracted the market value of that inventory change from the Sales figures. The reverse would be true for increases

in inventory. The Sales Value of Output should not be confused with Net Sales, which represents a firm's total sales as reported in its annual reports.

3. Operating Costs:

Operating costs include all costs and expenses, but exclude extraordinary gains or losses, interest expenses and taxes.

V. THE TEST

We have created various productivity measures at the domestic industry level (4-digit) and at the firm level (GM & Ford). Based upon the criteria of homogeneity, we have omitted measures which use physical units or measure labor without taking account of the heterogeneity among workers. Thus, the main thrust of our test will be for a business---how well a measure explains or captures productivity over time. We employ regression analysis using these measures as dependent variables and time as the independent variable. These regression analyses show us the trend of productivity over time and also how much of the variance is explained by time.

We hypothesize that time explains some of the variance of productivity measures, e.g. an upward trend because of experience curve effects, or a downward trend because of physical aging of capital. From a managerial point of view, however, time is not a controllable variable and therefore further research is necessary in order to assess the controllable dimensions of productivity.

After running the regressions, the distribution of the residuals of the various measures are checked for normality. Since we do not have an absolute standard against which to compare, we check for relative conformity to a normal distribution, i.e. we check which of the productivity measures gives the more efficient residual distribution.

Since we do not know the true value of the productivity estimator we cannot apply the MSE test. However, we will assume unbiased estimators and hence could apply the variance test:

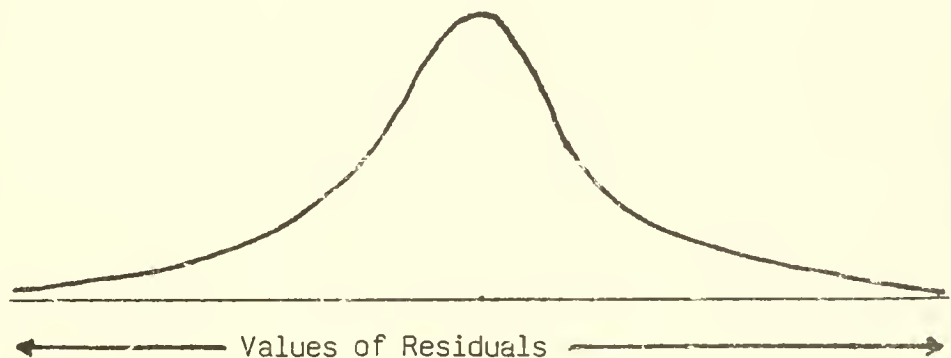
$$\text{efficiency} = \frac{\text{Var [Normal]}}{\text{Var [Residuals]}}$$

But this test is a C-square type of test which actually is a modified Chi-square test defined by

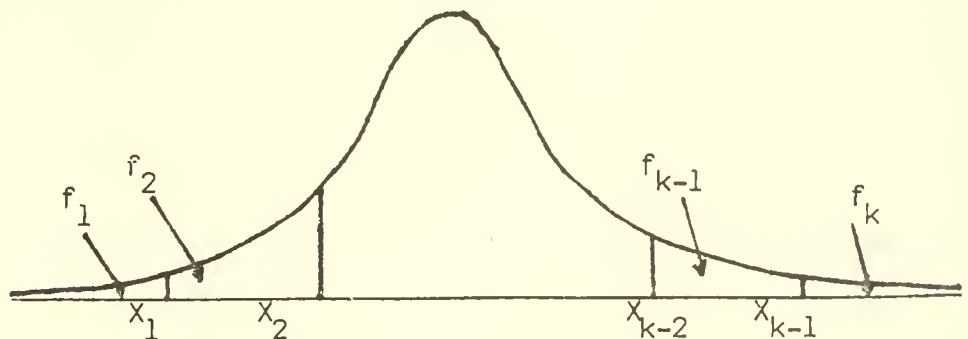
$$C\text{-square} = \frac{\text{Chi-square}}{\text{degrees of freedom}}$$

The Chi-square distribution has historically been used because of its many applications to goodness-of-fit tests. It is also useful in our case; since $\text{Var} [\text{Residuals}]$ is assumed to be an unbiased estimator of $\text{Var} [\text{Normal}]$, the expected value of each C-square distribution is one, within an interval of confidence.

We thus chose to employ the Chi-square test, which is, of course, equivalent to the C-square test, but which will consider the entire distribution of each residual. Let the histogram of our residual look like



Divide the values of residuals into k mutually exclusive intervals



such that the random variable X will move along the axis of x_k , or

$$X < X_1, X_1 \leq X < X_2, \dots \dots \dots X_{k-2} \leq X_{k-1}, X \leq X_{k-1}$$

and also

$$f_1 = \text{Number of observations for } X < X_1$$

$$f_2 = \text{Number of observations for } X_1 \leq X < X_2$$

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$$f_k = \text{Number of observations for } X \leq X_{k-1}$$

Note that in the application of our Chi-square test we have used X as the random variable and $X_{1,2,\dots,k}$ as constants, which is according to the notation of our statistical definitions on page 6-7 where $X_{1,2}$ are random variables.

In order to compare this distribution to a Normal one we estimate the probabilities P_i based on the sample maximum likelihood mean, M , and variance, S^2 , and the Chi-square tables for $(k-1)-2$ degrees of freedom. If we also let n be the size of the distribution of the residuals (number of observations), we have

$$P_1 = \Pr(X < X_1) = \Pr\left(\frac{X-M}{S} < \frac{X_1 - M}{S}\right)$$

$$P_2 = \Pr(X_1 \leq X < X_2) = \Pr\left(\frac{X_1 - M}{S} \leq \frac{X - M}{S} < \frac{X_2 - M}{S}\right)$$

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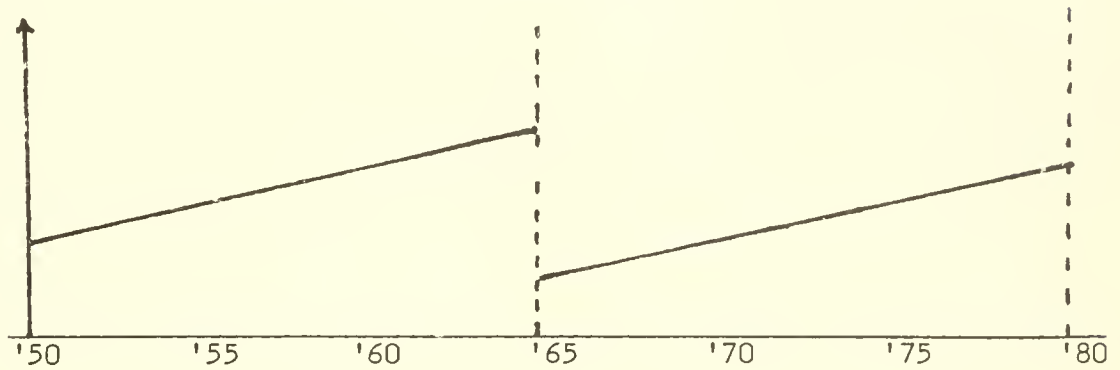
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$$P_k = \Pr(X \leq X_{k-1}) = \Pr(\frac{X - M}{S} \leq \frac{X_{k-1} - M}{S})$$

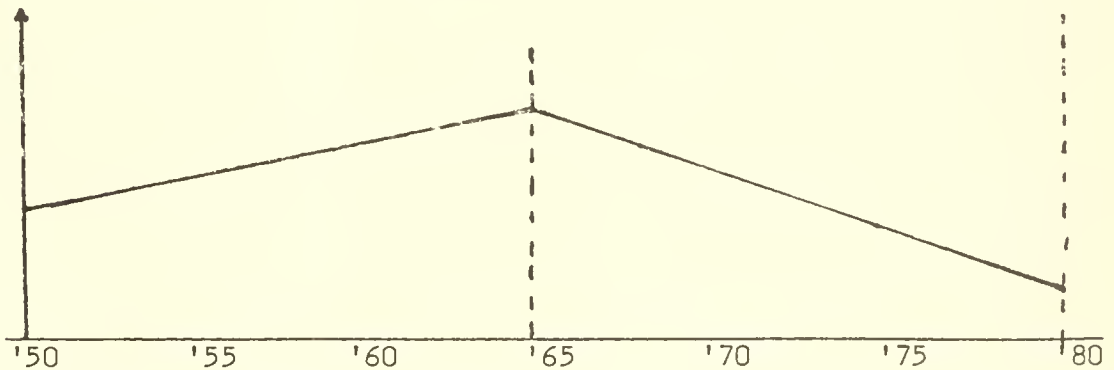
Next we employ,

$$\chi^2 = \sum_{i=1}^k \frac{(\text{Observed} - \text{Expected})^2}{\text{Expected}} = \sum_{i=1}^k \frac{(f_i - n \cdot p_i)^2}{n \cdot p_i}$$

The regression analysis may involve dummy variables and step-wise least squares (the same techniques are used for GNP calculations). For example, if we see that productivity measures plot against time as



we use dummy variables, i.e. (0,1). If they plot as



we use 2-step least squares.

We tested the measures using both industry level and firm level data. Since industry level data compiled by the Census of Manufactures takes account of the market value of inventory (as opposed to costs

alone) discussed earlier, these measures need no adjusting for this. However, this is not so at the firm level. To see if any differences ensue, we tested the firm level measures using unadjusted as well as adjusted data.

At the firm level, we have run tests on data from GM and Ford. While Chrysler results would be interesting, we have not tested measures with Chrysler data due to Chrysler's lack of consistency in accounting procedures and also to their aggregation of interindustry and international data which makes measurement and comparison difficult, if not meaningless.

TABLE 1
TEST OF MEASURES AT
DOMESTIC INDUSTRY LEVEL
FOR

S.I.C. 3717 (=3711 + 3714)

Measures	Yrs	Pattern	Outliers	2 R (linearized)	Coeffi- cient Value (B)	t (signif. level .05)	DW (autocor)	2 Chi 2 d.o.f.
$\frac{VA^*}{PB}$	1952 to 1977	'63 / \	1970 1971 1974	59% (1962-77)	-0.016	YES	NO	1.32
		'52 '77						
$\frac{VA^{**}}{WPW}$	1952 to 1977	'63 / \	1970 1971 1974	74% (1962-77)	-0.021	YES	NO	1.58
		'52 '77						
$\frac{VA^{***}}{HPW}$	1952 to 1977	'77 /	--- 1970	89% (1952-77)	+0.794	YES	YES (+)	2.11
		'52						

$$* \frac{VA}{PB} = \frac{\text{Value Added}}{\text{Payroll + Benefits}}$$

$$** \frac{VA}{WPW} = \frac{\text{Value Added}}{\text{Wages of Production Workers}}$$

$$*** \frac{VA}{HPW} = \frac{\text{Value Added}}{\text{Hours of Production Workers}}$$

VI. STATISTICAL RESULTS

A. Domestic Industry Level

1. S.I.C. 3717

The results from the analysis of the 3717 industry (motor vehicles and parts) are presented in Table 1. We observe that the value added over payroll and benefits measure, (VA/PB), shows a clear and important trend: productivity has consistently decreased after 1963. The value added over wages of production workers measure (VA/WPW) shows the the same trend, while the value added over hours or production workers measure (VA/HPW) indicates the opposite - an increase in productivity from 1952 to 1977.

The homogeneous value added measures have the same outliers, with both 1971 and 1974 on the high side. The BLS measure does not have significant outliers.

Time explains 59%, 74%, and 89% respectively of the variance of the three measures in the time intervals surveyed. The rate of change of productivity over time is negative and significant for the value added measures, whereas it is positive and significant for the BLS measure. Finally, the value added measures do not have autocorrelated residuals, whereas the BLS measure does. In terms of robustness with respect to the normality assumption the VA/PB measure is more robust than the other two.

2. S.I.C. 3715

The results from the analysis of the 3715 industry (trucks), which accounts for only 2% of the value added of the

TABLE 2
TEST OF MEASURES AT
DOMESTIC INDUSTRY LEVEL
FOR

S.I.C. 3715

1952 - 1977

Measures	Yrs	Pattern	Outliers	2 R (linearized)	Coeffi- cient Value (B)	t (signif. level .05)	DW (autocor)	2 Chi d.o.f.
$\frac{VA^*}{PB}$	1952 to 1977	'77 / '52	1953 1959 1972	75%	+0.018	YES	NO	7.28
$\frac{VA^{**}}{WPW}$	1952 to 1977	'77 / '52	1968 1972	67%	+0.026	YES	NO	2.92
$\frac{VA^{***}}{HPW}$	1952 to 1977	'77 / '52	---	85%	+0.412	YES	NO	3.25

$$* \frac{VA}{PB} = \frac{\text{Value Added}}{\text{Payroll + Benefits}}$$

$$** \frac{VA}{WPW} = \frac{\text{Value Added}}{\text{Wages of Production Workers}}$$

$$*** \frac{VA}{HPW} = \frac{\text{Value Added}}{\text{Hours of Production Workers}}$$

automobile industry as a whole (S.I.C. 371), are presented in Table 2. Here, all three measures indicate steadily increasing productivity during the years 1952 to 1977. This result is quite interesting. We could expect such results because we hypothesize that productivity is not a problem in the trucking industry. It may also indicate that the BLS measure accurately predicts productivity only under certain economic conditions.

B. Firm Level

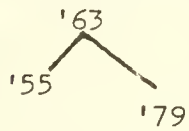
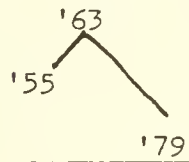
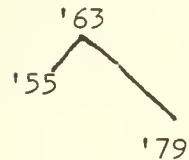
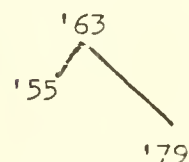
1. Unadjusted Value Added

The result for our test of unadjusted value added measures for GM and Ford are shown in Tables 3 and 4 on the pages following. The most striking results are the consistent patterns shown by all four value added measures, with peaks in 1959 for Ford and in 1963 for GM, followed by steady decline for both.

We also see that, regardless of the denominator used, all measures are consistent in having the same outliers for each company, these being 1967 and 1973 for Ford, and 1970 and 1974 for GM. We hope to investigate these outliers further in future research, but it appears at first blush that the 1967 and 1970 numbers are due to strikes, while those in 1973 and 1974 are related to the oil embargo shock.

The R^2 values for the regression models indicate that time is able to explain more of the variance of VA/OC for GM than the other measures and the least for VA/PB. At the same time, the R^2 measures for Ford are all quite close. Thus, while there is some variation for GM, all the value added measures are relatively robust in their specifications.

TABLE 3
TEST OF VALUE ADDED MEASURES
FOR
GENERAL MOTORS
(UNADJUSTED FOR INVENTORY MARGIN)

Measures	Yr	Pattern	Outliers	R ² (linearized) (1962-1979)	Coeffi- cient Value (β)	t (signif. level .05)	DW (autocor)	Chi ² 2 d.o.f.
$\frac{VA^*}{PB}$	1955 t 1979		1970 1974	62%	-0.024	YES	NO	4.79
$\frac{VA^{**}}{OC+D}$	1955 t 1979		1970 1974	79%	-0.006	YES	INDEC	7.88
$\frac{VA^{***}}{OC+CE}$	1955 t 1979		1970 1974	70%	-0.005	YES	YES (+)	5.55
$\frac{VA^{****}}{OC}$	1955 t 1979		1970 1974	82%	-0.007	YES	YES (+)	6.56

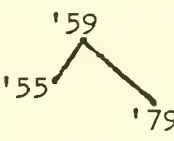
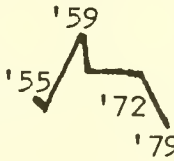
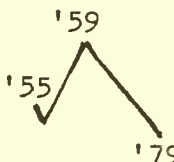
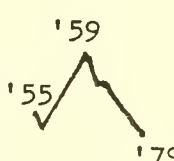
* $\frac{VA}{PB} = \frac{\text{Value Added}}{\text{Payroll} + \text{Benefits}}$

** $\frac{VA}{OC+D} = \frac{\text{Value Added}}{\text{Operating Costs} + \text{Depreciation}}$

*** $\frac{VA}{OC+CE} = \frac{\text{Value Added}}{\text{Operating Costs} + \text{Capital Expenditures}}$

**** $\frac{VA}{OC} = \frac{\text{Value Added}}{\text{Operating Costs}}$

TABLE 4
TEST OF VALUE ADDED MEASURES
FOR FORD
(UNADJUSTED FOR INVENTORY MARGIN)

Measures	Yrs	Pattern	Outliers	R ² (linearized) (1959-1979)	Coeffi- cient Value (B)	t (signif. level .05)	DW (autocor)	Chi ² 2 d.o.f
$\frac{VA^*}{PB}$	1955 to 1979		1967 1973	77%	-0.021	YES	NO	4.50
$\frac{VA^{**}}{OC+D}$	1955 to 1979		1967 1973	76%	-0.007	YES	INDEC	5.78
$\frac{VA^{***}}{OC+CE}$	1955 to 1979		1967 1973	74%	-0.007	YES	INDEC	4.85
$\frac{VA^{****}}{OC}$	1955 to 1979		1967 1973	77%	-0.008	YES	INDEC	5.85

$$* \frac{VA}{PB} = \frac{\text{Value Added}}{\text{Payroll + Benefits}}$$

$$** \frac{VA}{OC+D} = \frac{\text{Value Added}}{\text{Operating Costs + Depreciation}}$$

$$*** \frac{VA}{OC+CE} = \frac{\text{Value Added}}{\text{Operating Costs + Capital Expenditures}}$$

$$**** \frac{VA}{OC} = \frac{\text{Value Added}}{\text{Operating Costs}}$$

We can also see from the values of Betas and t , that the rate of change of productivity over time is negative and significant for all four measures for both GM and Ford. With respect to data autocorrelation we derived mixed results, which may attenuate some of our findings.

In terms of robustness with respect to the normality assumption, the VA/PB measure is the most robust exhibiting the lowest Chi-square of 4.79 for GM and 4.50 for Ford.

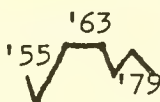
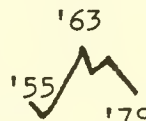
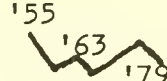
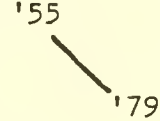
2. Unadjusted Sales

In Tables 5 and 6 we show the results for our test of unadjusted sales-type measures for GM and Ford. In terms of the pattern shown, while there is some variation from the value added results, all still demonstrate the same peaks of 1959 for Ford and 1963 for GM, and the ensuing decline until present. As well, approximately the same outliers are found. However, the results show sales-type measures not to be as desirable as value added measures. For GM the R^2 are generally quite low as is the R^2 for Sales/PB for Ford. Similarly, three of the four measures for GM and one for Ford show the rate of change in productivity over time to be insignificant.

3. Adjusted Value Added

When we adjusted the value added measure for the market value versus cost of inventory changes, we did not find an appreciable difference, generally speaking. We observe again that all the measures consistently show turning points in 1959 for Ford and 1963 for GM, all show the same outliers, and all show the rate of productivity change to be negative and significant (Tables 7 & 8).

TABLE 5
TEST OF SALES-TYPE MEASURES
FOR GENERAL MOTORS
(UNADJUSTED FOR INVENTORY MARGIN)

Measure	Test Period	Pattern	Outliers	² R (linearized) (1959-1979)	Coefficient Value (B)	t (signif. level .05)	DW (autocor)
<u>Sales*</u> PB	1955 to 1979	'55  '79	1970 1974	6%	-0.004	NO	YES
<u>Sales**</u> OC+D	1955 to 1979	'55  '79	1970 1974	0%	-0.0	NO	NO
<u>Sales***</u> OC+CE	1955 to 1979	'55  '79	1970 1974	4%	-0.0	NO	NO
<u>Sales****</u> OC	1955 to 1979	'55  '79	1970 1974	64%	-0.001	YES	INDEC

$$\frac{*Sales}{PB} = \frac{Value\ Added}{Payroll + Benefits}$$

$$\frac{**Sales}{OC+D} = \frac{Value\ Added}{Operating\ Costs + Depreciation}$$

$$\frac{***Sales}{OC+CE} = \frac{Value\ Added}{Operating\ Costs + Capital\ Expenditures}$$

$$\frac{****Sales}{OC} = \frac{Value\ Added}{Operating\ Costs}$$

TABLE 6
TEST OF SALES-TYPE MEASURES
FOR FORD
(UNADJUSTED FOR INVENTORY MARGIN)

Measure	Test Period	Pattern	Outliers	R ² (linearized) (1959-1979)	Coefficient Value (B)	t (signif. level .05)	DW (autocor)
<u>Sales*</u> PB	1955 to 1979	'55 '61 W '79 '60 '73	---	---	---	---	---
<u>Sales**</u> OC+D	1955 to 1979	'59 W '79 '55 '58	1965 1967 1974	55%	-0.002	YES	NO
<u>Sales***</u> OC+CE	1955 to 1979	'55 '59 W '79	1970 1967 1974	40%	-0.002	YES	NO
<u>Sales****</u> OC	1955 to 1979	'59 W '79 '55	1959 1965 1967 1974	86%	-0.003	YES	NO

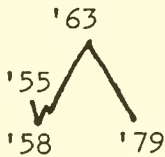
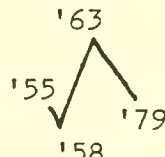
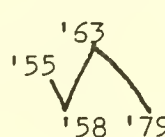
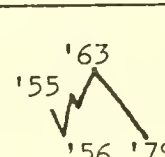
$$\frac{*Sales}{PB} = \frac{Value\ Added}{Payroll + Benefits}$$

$$\frac{**Sales}{OC+D} = \frac{Value\ Added}{Operating\ Costs + Depreciation}$$

$$\frac{***Sales}{OC+CE} = \frac{Value\ Added}{Operating\ Costs + Capital\ Expenditures}$$

$$\frac{****Sales}{OC} = \frac{Value\ Added}{Operating\ Costs}$$

TABLE 7
TEST OF VALUE ADDED MEASURES
FOR
GENERAL MOTORS
(ADJUSTED)

Measures	Yrs	Pattern	Outliers	R ² (linearized) (1962-1979)	Coeffi- cient Value (β)	t (signif. level .05)	DW (autocor)	Chi ² 2 d.o.f.
$\frac{VA^*}{PB}$	1955 to 1979		1970 1974 1975 1979	93%	-0.028	YES	NO	2.78
$\frac{VA^{**}}{OC+D}$	1955 to 1979		1970 1974	94%	-0.013	YES	NO	8.22
$\frac{VA^{***}}{OC+CE}$	1955 to 1979		1970 1974	92%	-0.012	YES	NO	2.19
$\frac{VA^{****}}{OC}$	1955 to 1979		1970 1974	95%	-0.015	YES	NO	4.97

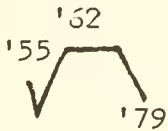
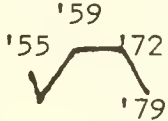
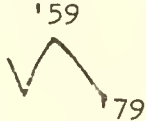
$$* \frac{VA}{PB} = \frac{\text{Value Added}}{\text{Payroll} + \text{Benefits}}$$

$$** \frac{VA}{OC+D} = \frac{\text{Value Added}}{\text{Operating Costs} + \text{Depreciation}}$$

$$*** \frac{VA}{OC+CE} = \frac{\text{Value Added}}{\text{Operating Costs} + \text{Capital Expenditures}}$$

$$**** \frac{VA}{OC} = \frac{\text{Value Added}}{\text{Operating Costs}}$$

TABLE 8
TEST OF VALUE ADDED MEASURES
FOR FORD
(ADJUSTED)

Measures	Yrs	Pattern	Outliers	R ² (linearized) (1959-1979)	Coeffi- cient Value (β)	t (signif. level .05)	DW (autocor)	Chi ² 2 d.o.f.
$\frac{VA^*}{PB}$	1955 to 1979		1967 1973	78%	-0.022	YES	NO	1.28
$\frac{VA^{**}}{OC+D}$	1955 to 1979		1967 1973	71%	-0.006	YES	NO	2.02
$\frac{VA^{***}}{OC+CE}$	1955 to 1979		1967 1973	72%	-0.008	YES	NO	6.82
$\frac{VA^{****}}{OC}$	1955 to 1979		1967 1973	76%	-0.010	YES	NO	7.79

$$* \frac{VA}{PB} = \frac{\text{Value Added}}{\text{Payroll} + \text{Benefits}}$$

$$** \frac{VA}{OC+D} = \frac{\text{Value Added}}{\text{Operating Costs} + \text{Depreciation}}$$

$$*** \frac{VA}{OC+CE} = \frac{\text{Value Added}}{\text{Operating Costs} + \text{Capital Expenditures}}$$

$$**** \frac{VA}{OC} = \frac{\text{Value Added}}{\text{Operating Costs}}$$

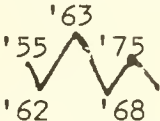
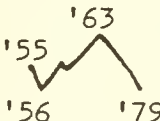
However, we do find some changes occurring when the adjustments are made. For example, we find positive autocorrelation occurring for two of the measures on the Ford data, and positive autocorrelation disappearing for the same measures on the GM data.

As to robustness with respect to the normality assumption the Chi-squares still show the VA/PB measure to be robust, although the VA/(OC+CE) measure became the most robust.

4. Adjusted Sales

The adjusted Sales measure demonstrate similar peaks and trends and outliers as the other measures. However, by performing the adjustment, the goodness -of-fit is improved in every case. Similarly, more measures become significant, going from one to four for GM and remaining four out of four for Ford (Tables 9 & 10).

TABLE 9
TEST OF SALES-TYPE MEASURES
FOR GENERAL MOTORS
(ADJUSTED)

Measure	Test Period	Pattern	Outliers	² R (linearized) (1959-1979)	Coefficient Value (B)	t (signif. level .05)	DW (autocor)
<u>Sales*</u> PB	1955 to 1979		1970	14%	-0.009	YES (barely)	YES
<u>Sales**</u> OC+D	1955 to 1979		1970 1974	84%	-0.009	YES	NO
<u>Sales***</u> OC+CE	1955 to 1979		1970 1974	79%	-0.008	YES	NO
<u>Sales****</u> OC	1955 to 1979		1970 1974	94%	-0.013	YES	NO

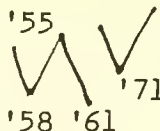
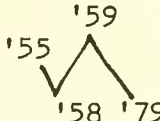
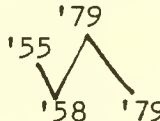
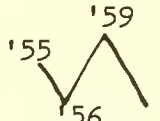
$$\frac{*Sales}{PB} = \frac{Value\ Added}{Payroll + Benefits}$$

$$\frac{**Sales}{OC+D} = \frac{Value\ Added}{Operating\ Costs + Depreciation}$$

$$\frac{***Sales}{OC+CE} = \frac{Value\ Added}{Operating\ Costs + Capital\ Expenditures}$$

$$\frac{****Sales}{OC} = \frac{Value\ Added}{Operating\ Costs}$$

TABLE 10
TEST OF SALES-TYPE MEASURES
FOR FORD
(ADJUSTED)

Measure	Test Period	Pattern	Outliers	² R (linearized) (1959-1979)	Coefficient Value (θ)	t (signif. level .05)	DW (autocor)
<u>Sales*</u> PB	1955 to 1979	'55  '58 '61	1967	--	---	--- (barely)	---
<u>Sales**</u> OC+D	1955 to 1979	'55  '58 '79	1967 1974	90%	-0.005	YES	NO
<u>Sales***</u> OC+CE	1955 to 1979	'55  '58 '79	1967 1974 1979	74%	-0.006	YES	YES (+)
<u>Sales***</u> OC	1955 to 1979	'55  '56	1967 1974	95%	-0.008	YES	NO

$$\frac{*Sales}{PB} = \frac{Value\ Added}{Payroll + Benefits}$$

$$\frac{**Sales}{OC+D} = \frac{Value\ Added}{Operating\ Costs + Depreciation}$$

$$\frac{***Sales}{OC+CE} = \frac{Value\ Added}{Operating\ Costs + Capital\ Expenditures}$$

$$\frac{****Sales}{OC} = \frac{Value\ Added}{Operating\ Costs}$$

VII. CONCLUSIONS

Our analysis shows that of the homogeneous (dollar output over dollar input) measures, the value added over payroll and benefits measure and the value added over operating costs and capital expenditures measure hold most promise, in terms of both robustness and validity, in explaining productivity changes over time.

Of course, we have looked until now at the left hand side of the productivity equation. We think that we can now hypothesize that productivity changes due to internal efficiency will be better explained by using value added over payroll & benefits as the dependent variable, whereas productivity changes due to strategic/external effectiveness will better explained by using value added over operating cost and capital expenditures as the dependent variable. The determination of the independent variables, the dimensions of productivity, is the subject of our next task.

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